

The Absolute Parameters of The Detached Eclipsing Binary V482 Per

Ö. Baştürk^{a,*}, S. Zola^{b,c}, A. Liakos^d, R. H. Nelson^e, K. Gazeas^f, İ. Özavcı^a,
M. Yılmaz^a, H. V. Şenavcı^a, and B. Zakrzewski^c

^a*Ankara University, Faculty of Science, Department of Astronomy and Space Sciences,
TR-06100, Tandoğan, Ankara, Turkey*

^b*Astronomical Observatory, Jagiellonian University, ul. Orla 171, PL-30-244 Krakow,
Poland*

^c*Mt Suhora Observatory, Pedagogical University, ul. Podchorazych 2, PL-30-084
Krakow, Poland*

^d*Institute for Astronomy and Astrophysics, Space Applications and Remote Sensing,
National Observatory of Athens, Penteli, Athens, Greece*

^e*1393 Garvin Street, Prince George, BC V2M 3Z1, Canada*

^f*Department of Astrophysics, Astronomy and Mechanics, National & Kapodistrian
University of Athens, Zografos, Athens, Greece*

Abstract

We present the results of the spectroscopic, photometric and orbital period variation analyses of the detached eclipsing binary V482 Per. We derived the absolute parameters of the system ($M_1 = 1.51 M_\odot$, $M_2 = 1.29 M_\odot$, $R_1 = 2.39 R_\odot$, $R_2 = 1.45 R_\odot$, $L_1 = 10.15 L_\odot$, $L_2 = 3.01 L_\odot$) for the first time in literature, based on an analysis of our own photometric and spectroscopic observations. We confirm the nature of the variations observed in the system's orbital period, suggested to be periodic by earlier works. A light time effect due to a physically bound, star-sized companion ($M_3 = 2.14 M_\odot$) on a highly eccentric ($e = 0.83$) orbit, seems to be the most likely cause. We argue

*Corresponding author. Tel.: +90 312 2126720; fax +90 312 2232395

Email address: obasturk@ankara.edu.tr (Ö. Baştürk)

that the companion can not be a single star but another binary instead. We calculated the evolutionary states of the system's components, and we found that the primary is slightly evolving after the Main Sequence, while the less massive secondary lies well inside it.

Keywords:

Stars: binaries: eclipsing; stars: fundamental parameters; stars: individual (V482 Per)

1. Introduction

The mass of a star is the single most important parameter which determines the way it lives and dies and what remains from it after its death. It can only be directly and precisely determined with the analysis of the light and radial velocity variations occurring due to the orbital motion of the components of an eclipsing binary system. Since each component of a binary is confined to the space that we call the Roche lobe, its evolution will be different from that of a single star once it fills this space. Mass transfer occurs between the two after contact has been made and disturbs the evolution of the components as single stars. Detached binaries are the systems whose components have not filled their Roche lobes yet and thus evolve as single stars. Therefore the components of detached eclipsing binaries with well determined parameters have been regularly used to test the stellar evolution models.

V482 Per (BD+47° 961, GSC 3332-314) is a detached eclipsing binary which was first observed and classified as a short period variable by Hoffmeister (1966). Harvig & Leis (1981) investigated this star based on archival photo-

graphic plates. They classified it as an eclipsing system, found its magnitude, and published the first light-curve and its elements. Agerer & Lichtenknecker (1991), based on their first photoelectric observations, published B and V light curves and the B-V color curve of V482 Per. Popper (1996) found a mean spectral type of F2 for V482 Per by using equivalent widths of the Na-D line of both components. In the same study he pointed to the discrepancy between the photometric study by Agerer & Lichtenknecker (1991), which implied a middle-F spectral type for the primary, and the weakness of the Na-D lines in his spectra from which he determined an earlier spectral type. V482 Per was also found to be a close binary in a triple system from the light-time effect observed on its O-C diagram. This subject was discussed by Wolf et al. (2004) and Ogloza et al. (2012), both of whom gave very similar values of the basic parameters of the third body (P_3 and e).

In 2011, we acquired precise photometric measurements of the system in Gerostathopoulion Observatory of the University of Athens. We also obtained spectroscopic data for the system in order to determine its orbital parameters and the ratio of the masses of its components. We performed an analysis using the Wilson-Devinney (Wilson & Devinney, 1971; Wilson, 1990; Kallrath et al., 1998) model of our light curves based on our spectroscopically determined mass ratio of the system. As a result, for the first time we derived its absolute parameters (masses, radii, and luminosities) for both of the spectral types (F2 and F5) suggested by earlier works of Agerer & Lichtenknecker (1991) and Popper (1996). For the best fit we needed to include a third light, which would also support the triple-system hypothesis of earlier works by Wolf et al. (2004) and Ogloza et al. (2012).

We have performed an O-C analysis to ensure that an expected orbital variation is actually observed. Consequently, we confirmed the existence of a physically bound, stellar size third body and determined its parameters.

2. Observations and Data Reduction

Between October and December 2011 (in 13 nights), we obtained multicolor photometric data for V482 Per with the 40 *cm* Cassegrain telescope located at the Gerostathopoulion Observatory of the University of Athens. The telescope's focal ratio was converted to f/5.1 from f/8 by using a focal reducer. It was equipped with an SBIG ST-10 XME CCD detector and a set of Johnson-Cousins *BVRI* filters. We present a log of these observations in Table-1. We have corrected all the CCD images for instrumental effects, using the C-munipack (Hroch, 1998; Motl, 2004) software package. Next we performed differential aperture photometry with the same software, which allowed us to experiment with different aperture sizes until we achieved a relatively low scatter. Individual differential magnitudes were derived with respect to a chosen comparison star (GSC 3332-2173), the stability of which was tested against a check star (GSC 3332-1993). We constructed the light curves using these differential magnitudes in each filter and the light elements that we calculated from a linear fit to the previously published times of minima.

One of the authors of this study (RHN), carried out spectroscopic observations at the Dominion Astrophysical Observatory (DAO) in Victoria, British Columbia, Canada, using the Cassegrain spectrograph attached on the 1.85 m Plaskett telescope with a grating (#21181) of 1800 lines/mm,

Table 1: Information About The Observations

Log of The Observations		
Dates of Observation (in 2011)	17,19,20,31 Oct	
	1, 2, 3, 8, 16, 19, 26 Nov	
	1, 4 Dec	
# of Data Points	1630 (B), 1597 (V), 1614 (R), 1549 (I)	
Mean Errors (σ)	0.0031 (B), 0.0031 (V), 0.0031 (R), 0.0027 (I)	
Star	m_V (mag)	B-V (mag)
Variable (V482 Per)	10.30	0.40
Comparison (GSC 3332-2173)	9.63	0.32
Check (GSC 3332-1993)	11.1	0.40
Light elements employed to phase the observations		
Reference Epoch (in HJD)	2455868.4005	
Orbital Period	$2^d.44677$	

blazed at 5000 Å giving a reciprocal linear dispersion of 10 Å/mm in the first order and covering a wavelength region from 5000 to 5260 Å. The reductions (cosmic hit removal, median background fitting and subtraction for each wavelength, aperture summation, and continuum normalization) were performed with the 'RaVeRe' software (Nelson, 2010). The same software was used for wavelength calibration and linearization using the Fe-Ar spectra as wavelength standards. The five spectra we used are depicted in Fig. 1

In order to obtain radial velocity measurements we applied the Rucinski broadening functions (Rucinski, 2004; Nelson et al., 2006; Nelson, 2010) (Fig. 2). We phased these observations with the same light elements that we used to calculate orbital phases of our photometric measurements, after having converted all the observation times to heliocentric values. We found the gamma velocity (V_γ) of the system to be -22.72 (± 3.05) km/s. The resultant radial velocity curves for each of the components and the best fits to them are

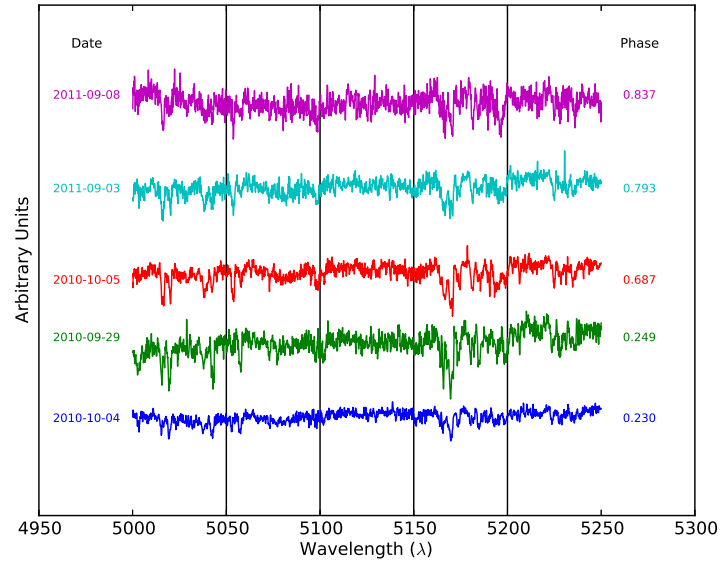


Figure 1: The spectra used in radial velocity analysis. Four individual spectra are shifted arbitrarily for clarity.

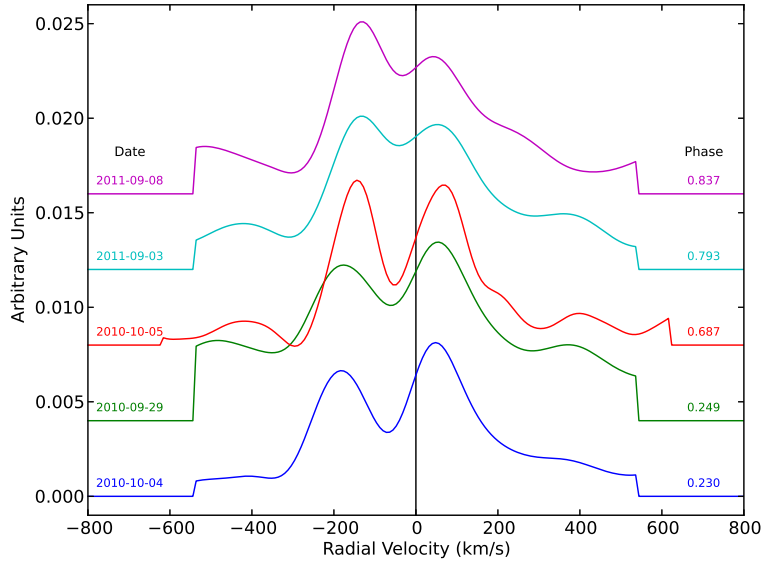


Figure 2: Broadening functions used to determine radial velocities. Some of the functions are shifted arbitrarily for clarity.

given in Fig. 3. We determined semi-amplitudes of each of the fitted curves (K_1 and K_2) and computed the spectroscopic mass ratio of the system ($q = m_s/m_p = K_1/K_2 = 0.856$).

3. The Light Curve Analysis

We used the Wilson-Devinney code (WD) (Wilson & Devinney, 1971; Wilson, 1990; Kallrath et al., 1998) to derive parameters of components of V482 Per. Instead of using all the individual observations, approximately 150 mean points were used to speed up computations. They were calculated in such a way that they evenly covered the observed light curve. In order

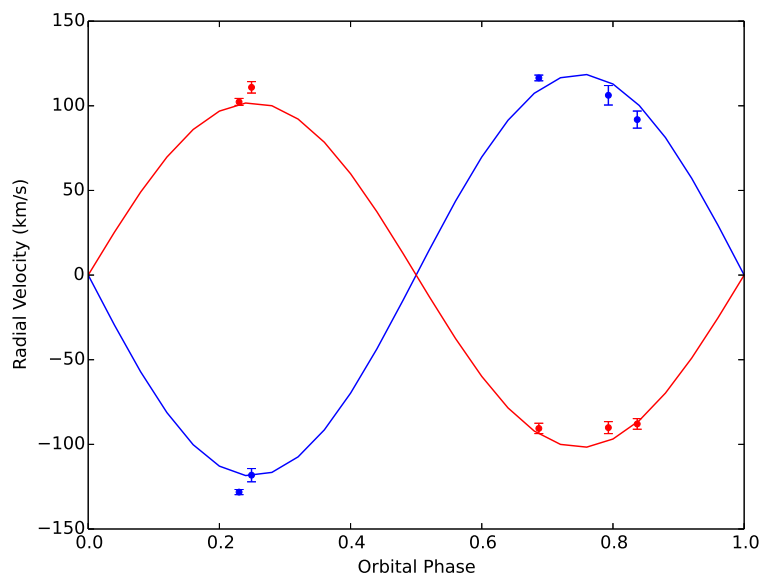


Figure 3: Radial velocity data for V482 Per and the best fits in solid lines.

to make sure that the global minimum was found within the set ranges of free parameters, we made use of the Monte Carlo search algorithm. We followed the procedure outlined in Zola et al. (2014), in which the mass ratio is fixed to the spectroscopically determined value. The albedo and gravity darkening coefficients were set at their theoretical values for a convective envelope (0.5 and 0.32, respectively) suitable for both F2 and F5 spectral types (van Hamme, 1993). The limb darkening coefficients were taken from the tables by Claret & Bloemen (2011), Claret et al. (2012) and Claret et al. (2013) and were built into the code. They were selected according to the temperature and the wavelength of the observations. We adjusted the inclination, temperature of the secondary, surface potentials, and the luminosity of the primary component. We made checks for all three existing spectral types of this systems: F2 given by Popper (1996), F5 derived by Agerer & Lichtenknecker (1991) from the B-V color and A0 listed in the SIMBAD database. Due to a possibility that this system has a companion, third light was added into the model. We fixed the temperature of the primary at the values of 6700 K, 6460 K and 9420 K, corresponding to the three spectral types according to the calibration given by Harmanec (1988) and achieved three solutions. It soon turned out that the model with the assumed A0 spectral type of the primary resulted in highly overluminous values for their masses. Therefore, this solution was discarded.

The configuration of the system was found to be detached with both components to be well within their Roche lobes. We obtained a good fit to the observed light curves with just small discrepancies in the phase range between 0.30-0.45. We derived a small contribution of the third light, ranging

Table 2: Best-fit parameters from Wilson-Devinney light curve modelling.

Stellar Parameters	F2		F5	
	Value	Error	Value	Error
T_1 [K]	6700	Fixed	6460	Fixed
T_2 [K]	6340	18	6130	17
Ω_1	5.38	0.04	5.39	0.04
Ω_2	7.42	0.15	7.38	0.15
$q = m_2/m_1$	0.856	Fixed	0.856	Fixed
i [°]	83.2	0.3	83.2	0.3
Luminosities				
L_1 [B]	9.68	0.33	9.63	0.34
L_1 [V]	9.07	0.33	9.06	0.34
L_1 [R]	8.92	0.32	8.91	0.33
L_1 [I]	8.79	0.32	8.72	0.34
L_2 [B]	2.75	0.09	2.80	0.09
L_2 [V]	2.71	0.08	2.71	0.08
L_2 [R]	2.74	0.08	2.75	0.08
L_2 [I]	2.78	0.09	2.82	0.09
l_3 [B]	0.01	0.02	0.01	0.03
l_3 [V]	0.05	0.03	0.05	0.03
l_3 [R]	0.06	0.02	0.06	0.03
l_3 [I]	0.07	0.02	0.07	0.03

Note: $T_{1,2}$ - temperature of the primary and secondary, $\Omega_{1,2}$ - dimensionless surface potentials of the components, $q = m_2/m_1$ - the system mass ratio, i - orbit inclination (in degrees), $L_{1,2}$ - WD code luminosities, l_3 - third light

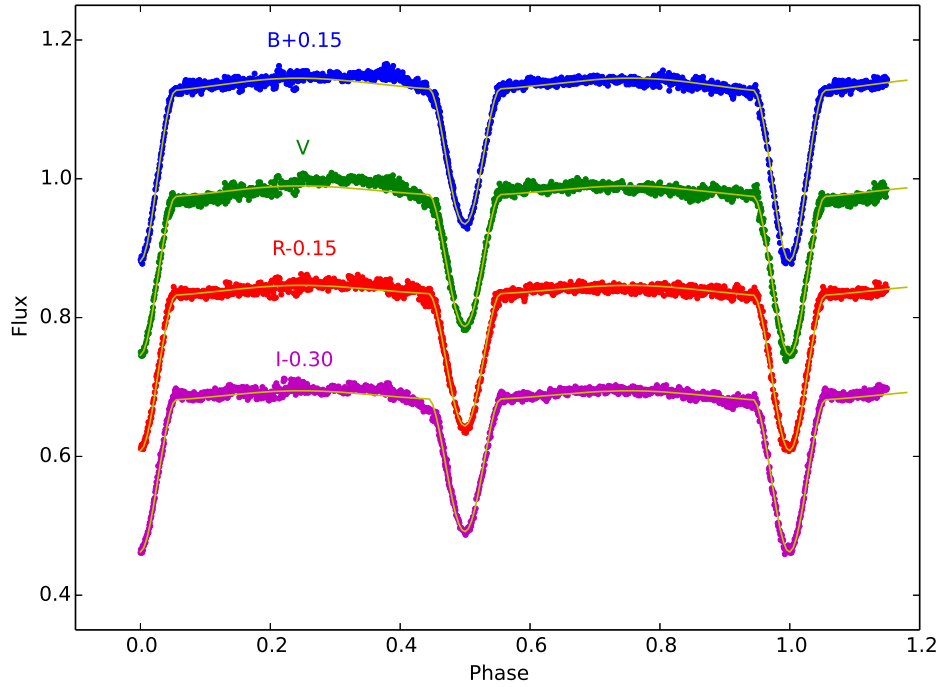


Figure 4: Comparison between observations of V482 Per (BVRI filters - shown from top to bottom - shifted arbitrarily for clarity by the amounts given in the figure) and the best fits (solid lines) obtained for the F2 spectral type.

from 1 to 7%, depending on the passband.

The results derived from the light curve modeling are presented in Table 2, while model light curves along with observations are shown in Figs. 4 & 5 for both F2 and F5 spectral types, respectively.

4. Eclipse Timing Analysis

V482 Per has been known to display orbital period variations, which were suggested to be of a periodic nature (Wolf et al., 2004; Ogloza et al.,

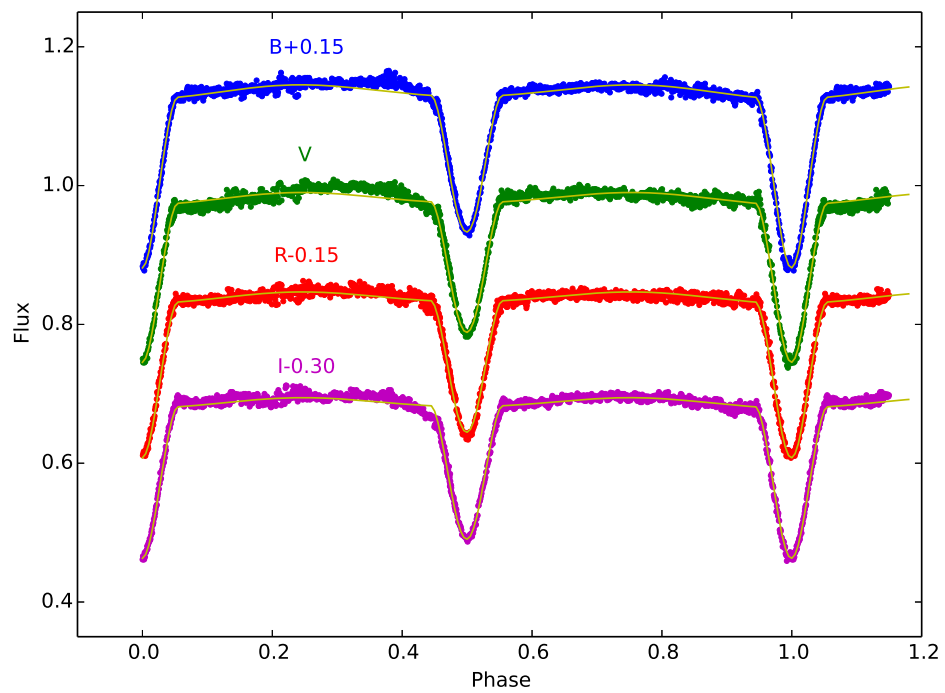


Figure 5: The same as the Fig.4 but for the spectral type F5.

Table 3: Results of the eclipse timing analysis.

Parameter	Value	Error
P_3 [years]	16.56	0.11
A [days]	0.018	0.001
ω [$^\circ$]	206	2
e	0.83	0.02
$a_3 \sin(i)$ [AU]	4.74	0.22
$f(m_3)$ [M_\odot]	0.39	0.06
m_3 [M_\odot]	2.14	0.05

2012). We have collected all available eclipse times published in the literature (Appendix A) including these determined from our data (Liakos & Niarchos, 2011) and constructed an O-C diagram (Fig. 6). We confirmed that the variations are in fact periodic and most likely they can be caused by the light time effect due to a third body gravitationally bound to the system on an eccentric orbit. We made use of Irwin’s formalism (Irwin, 1952, 1959) during our analysis, and obtained the parameters of the third body presented in Table-3 as a result.

5. Results & Discussion

We have analyzed light and radial velocity curves, and the long term orbital period variations of the detached system V482 Per. We have derived two sets of absolute parameters (Table-4) as a result of the first ever combined analysis of its photometric and spectroscopic observations. One set of solutions was based on the spectral type F5 given by Agerer & Lichtenknecker

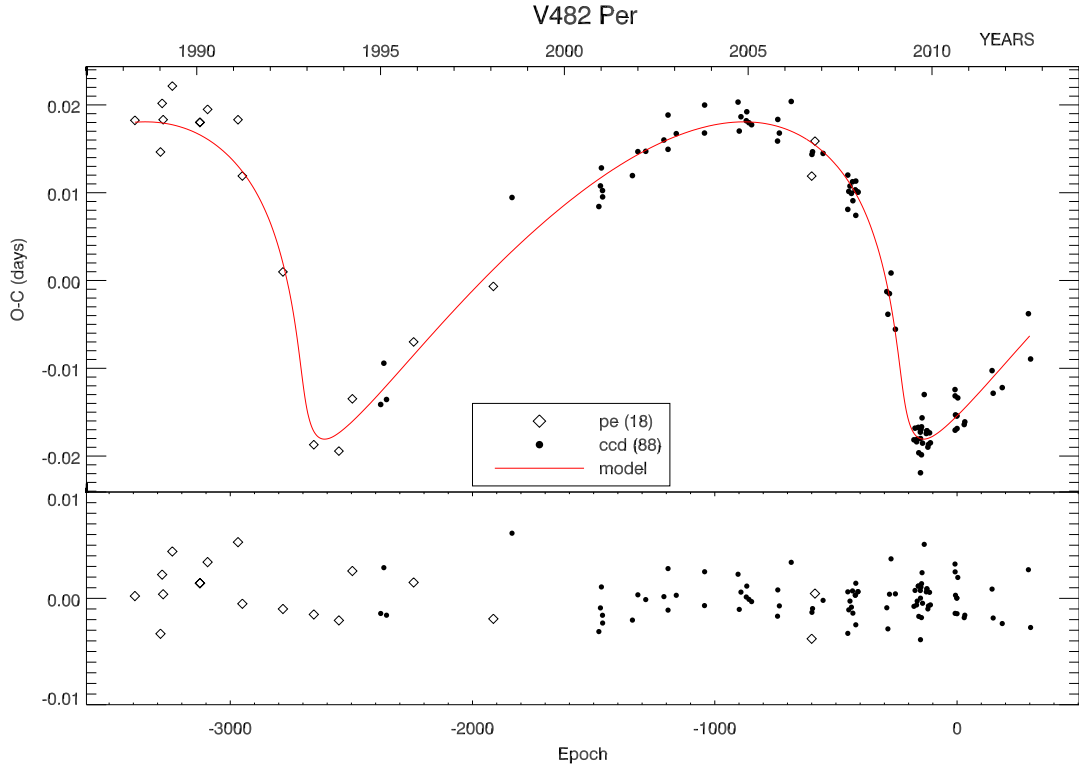


Figure 6: Period variation behavior of V482 Per. The best fit is shown as solid line. Residuals from the fit are given in the lower panel. The symbols used have been defined in the legends. Times of minima are listed in the Appendix A together with their references.

(1991) and the other was based on F2 spectral type given by Popper (1996). We used the web interface to query Geneva Stellar Models' database (Ekström et al., 2012) and computed evolutionary tracks for three different masses (1.3, 1.5, 1.7 M_{\odot}) in close proximity to the derived masses of V482 Per's components ($M_p = 1.51 M_{\odot}$, $M_s = 1.29$). The stellar evolutionary models have been taken from a dense grid for low mass stars assuming no rotation and for the solar metallicity (Mowlavi et al., 2012).

We next constructed the Hertzsprung-Russell (HRD), Mass-Luminosity (MLD), and Mass-Radius (MRD) Diagrams (Figs. 7 & 8) based on the parameters we obtained from our analysis for V482 Per, and the tracks from the models. We have given the positions of both components for each of the two solutions in the HRD (Fig. 7) with filled (primaries) and unfilled (secondaries) circles (F2) and squares (F5). The evolutionary model tracks for the three chosen masses are also drawn by solid lines in the HRD. Since masses of the components do not depend on the assumed temperature of the primary, and both solutions resulted in almost the same values for the radii of components, only parameters resulting from the F2 spectral type model are presented in the MRD (right panel of Fig .8). However, due to the different temperatures of the components between the two solutions, there is a difference in luminosities of about 12%, which is shown in the MLD by giving both of the solutions (left panel of Fig. 8).

The positions of V482 Per's components in all evolution diagrams in Figs. 7 & 8 indicate the primary to be somewhat evolved (just above the TAMS) and more luminous than expected for its mass. This statement is true for solutions obtained for both spectral types assumed. Based on the position

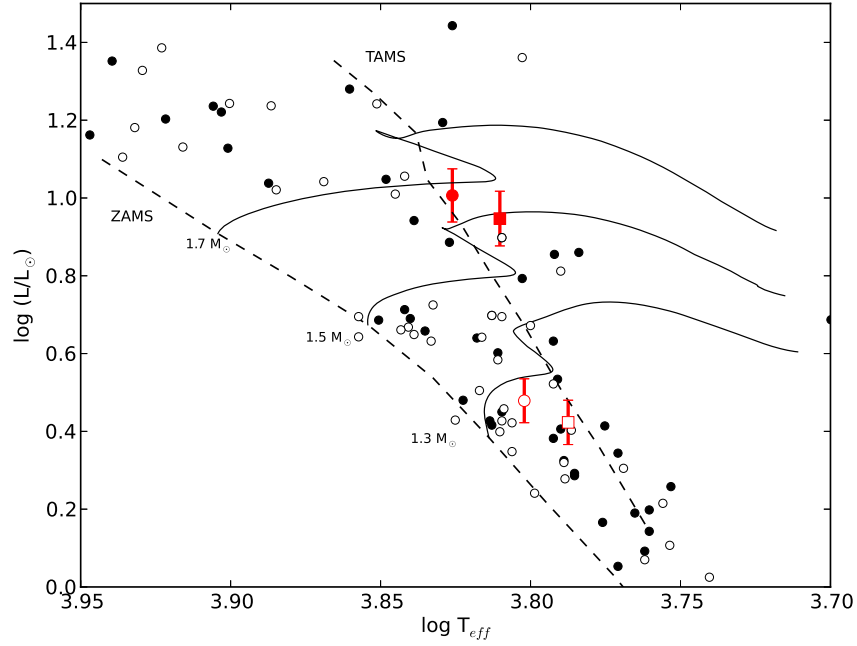


Figure 7: A Hertzsprung-Russell Diagram with the positions of selected detached (primaries in filled, secondaries in unfilled grey circles) from Torres et al. (2010). Positions of the components of the system V482 Per are marked with larger symbols (circles show F2-spectral type solution, squares that of F5). The evolutionary tracks for a dense grid of masses, computed by interpolation between the existing tracks of the Geneva stellar models (Mowlavi et al., 2012) are plotted with solid lines while ZAMS and TAMS are in dashed lines.

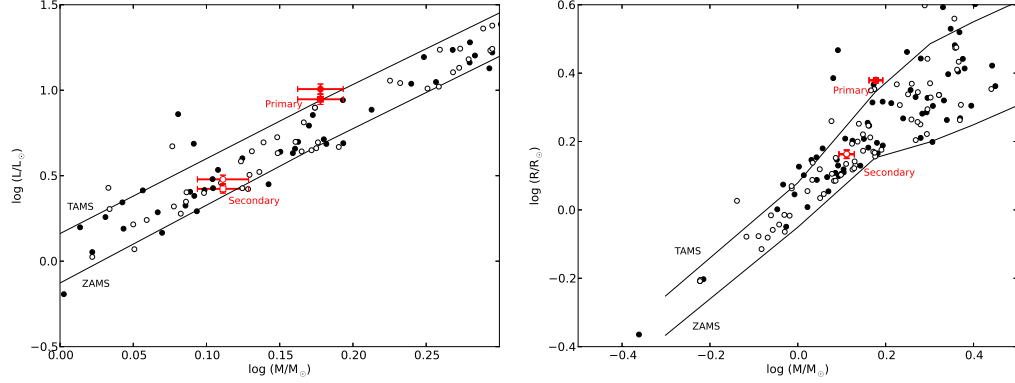


Figure 8: Mass-Luminosity (left panel) and Mass-Radius (right panel) diagrams. ZAMS and TAMS computed from the theoretical models by Mowlavi et al. (2012) are plotted by solid lines. Positions of components in selected detached systems from Torres et al. (2010) are also shown. Symbols mean the same as in Fig. 7.

of the secondary (see Figs. 7 and 8), it is evolving on the Main Sequence, about half way between ZAMS and TAMS. It seems that a better agreement with the evolutionary models was obtained for the hotter, F2 type primary model. Within the F5 solution the secondary is significantly underluminous (see Figs. 7 and 8).

Our analysis of the system's O-C diagram provides a strong evidence for the existence of a third body, proposed in earlier works of Wolf et al. (2004), and Ogloza et al. (2012). Knowing the absolute parameters of the system's components, and assuming a coplanar orbit with the binary, we found the companion to have a very close lower mass limit ($2.14 M_{\odot}$) to their estimates based on guessed absolute parameters of the system. The orbital period (~ 16 years), eccentricity (~ 0.83) and the size of the gravitationally

Table 4: Absolute Parameters

Parameter	F2 model		F5 model	
	Value	Error	Value	Error
$a[R_{\odot}]$	10.76	0.16	10.76	0.16
$M_1[M_{\odot}]$	1.51	0.05	1.51	0.05
$M_2[M_{\odot}]$	1.29	0.05	1.29	0.05
$R_1[R_{\odot}]$	2.39	0.04	2.40	0.04
$R_2[R_{\odot}]$	1.45	0.04	1.46	0.04
$L_1[L_{\odot}]$	10.15	0.69	8.85	0.62
$L_2[L_{\odot}]$	3.01	0.17	2.65	0.15

Note: a - orbital semi-major axis in units of solar radius, $M_{1,2}$ - masses, $R_{1,2}$ - radii, $L_{1,2}$ - luminosities of the primary and secondary, respectively.

bound component's orbit are also very similar in both of these studies and ours. We confirm their findings based on the absolute parameters determined from combined spectroscopy and photometry analysis. The $2.14 M_{\odot}$ tertiary companion would be an A1 type star with about 9100 K temperature and a radius of $2.02 R_{\odot}$. Its luminosity would be about $25.5 L_{\odot}$, twice exceeding that of the binary system. However, we found a very small contribution reaching about 7% in the I filter and decreasing towards shorter wavelengths. From a crude estimate it follows that the companions should have about $1 L_{\odot}$ in the near infrared and smaller in shorter wavelengths. Unfortunately, we haven't seen a trace of a third body in the spectra which might be due to our resolution limit. As an explanation, a binary system consisting of a dwarf and a compact object would agree with our findings. Further radial velocity

observations are needed to verify this hypothesis.

Acknowledgments

The authors acknowledge the use of the Simbad database, operated at the CDS, Strasbourg, France, and of NASA's Astrophysics Data System Bibliographic Services. We would like to thank all the staff working for Dominion Astrophysical Observatory and Gerostathopoulion Observatory of the University of Athens. SZ gratefully acknowledges the support by the NCN grant No. 2012/07/B/ST9/04432.

References

- Agerer, F., Dahm, M., Hübscher, J., 1999, IBVS, 4712
- Agerer, F., Hübscher, J., 1995, IBVS, 4222
- Agerer, F., Hübscher, J., 1996, IBVS, 4383
- Agerer, F., Hübscher, J., 1997, IBVS, 4472
- Agerer, F., Hübscher, J., 1998, IBVS, 4562
- Agerer, F., Hübscher, J., 2003, IBVS, 5484
- Agerer, F., Lichtenknecker, D., 1991, IBVS, 3554
- Brát, L., Zejda, M., Svoboda, P., 2007, OEJV, 74
- Claret, A., Bloemen, S., 2011, A&A, 529, 75.
- Claret, A., Hauschildt, P. H., Witte, S., 2012, A&A, 546, 14

- Claret, A., Hauschildt, P. H., Witte, S., 2013, A&A, 552, 16
- Diethelm, R., 2009, IBVS, 5894
- Diethelm, R., 2011a, IBVS, 5960
- Diethelm, R., 2011b, IBVS, 5992
- Diethelm, R., 2013, IBVS, 6042
- Ekström, S., Georgy, C., Eggenberger, P., Meynet, G., Mowlavi, N., Wyttenbach, A., Granada, A., Decressin, T., Hirschi, R., Frischknecht, U., Charbonnel, C., Maeder A., 2012, A&A, 537, A146.
- Harmanec, P., 1988, BAICz, 39, 329.
- Harvig, V., Leis L., 1981, PTarO, 48, 172.
- Hoffmeister, C., 1966, AN, 289, 1.
- Hoch, F., 1998, Proceedings of the 29th Conference on Variable Star Research, 30.
- Hübscher, J., Agerer, F., Rückersdorf, E.W., 1991, BAVSM, 59
- Hübscher, J., Agerer, F., Wunder, E., 1992, BAVSM, 60
- Hübscher, J., Agerer, F., Wunder, E., 1993, BAVSM, 62
- Hübscher, J., Agerer, F., Frank, P., Wunder, E., 1994, BAVSM, 68
- Hübscher, J., Steinbach, H.-M., Walter, F., 2009a, IBVS, 5874
- Hübscher, J., Steinbach, H.-M., Walter, F., 2009b, IBVS, 5889

Hübscher, J., Lehmann, P. B., Walter, F., 2012, IBVS, 6010

Hübscher, J., Walter, F., 2007, IBVS, 5761

Irwin, J. B., 1952, ApJ, 116, 211

Irwin, J. B., 1959, AJ, 64, 149

Kallrath, J., Milone, E. F., Terrell, D. Y., Andrew T., 1998, ApJ, 508, 308

Lacy, C.H.S., 2002, IBVS, 5357

Lacy, C.H.S., 2003, IBVS, 5487

Lacy, C.H.S., 2004, IBVS, 5577

Lacy, C.H.S., 2006, IBVS, 5670

Lacy, C.H.S., 2007, IBVS, 5764

Lacy, C.H.S., 2009, IBVS, 5910

Lacy, C.H.S., 2011, IBVS, 5972

Lacy, C.H.S., 2012, IBVS, 6014

Lacy, C.H.S., 2013, IBVS, 6046

Kotkova, L., Wolf, M., 2006, IBVS, 5676

Liakos, A., Niarchos, P., 2011, IBVS, 6005

Motl, D., 2004, C-MUNIPACK, <http://c-munipack.sourceforge.net/>.

- Mowlavi, N., Eggenberger, P., Meynet, G., Ekström, S., Georgy, C., Maeder, A., Charbonnel, C., Eyer, L., 2012, A&A, 541, 41.
- Nelson, R.H., Terrell, D., Gross, J., 2006. IBVS 5715, 1.
- Nelson, R.H., 2010a, Software by Bob Nelson.
(<http://members.shaw.ca/bob.nelson/software1.htm>).
- Nelson, R.H., 2010b, 'Spectroscopy for Eclipsing Binary Analysis' in The Alt-Az Initiative, Telescope Mirror & Instrument Developments (Collins Foundation Press, Santa Margarita, CA). R.M. Genet, J.M. Johnson and V. Wallen (eds).
- Ogoza, W., Kreiner, J. M., Stachowski, G., Winiarski, M., Zakrzewski, B., Dogru, S., Alicavus, F., Demircan, O., Erdem, A., 2012, IAUS, 282, 850.
- Popper, D. M., 1996, ApJS, 106, 133.
- Paschke, A., 1999, O-C Gateway, <http://var.astro.cz/ocgate/>
- Rucinski, S.M., 2004. IAUS 215, 17.
- Torres, G., Andersen, J., Giménez, A., 2011, A&ARv, 18, 67
- van Hamme, W., 1993, AJ, 106, 296
- Wilson, R. E., Devinney, E. J, 1971, ApJ, 166, 605.
- Wilson, R. E., 1990, ApJ, 356, 613.
- Wolf, M., Mayer, P., Zasche, P., Sarounova, L., Zejda, M., 2004, ASPC, 318, 255.

Yılmaz, M., Baştürk, Ö., Alan, N., and 13 co-authors, 2009, IBVS, 5887

Zejda, M., 2004, IBVS, 5583

Zola, S., Şenavcı, H. V., Liakos, A., Nelson, R. H., Zakrzewski, B., 2014,
MNRAS, 437, 3718.

Appendix A.

Table A.1: Eclipse Timings for V482 Per

HJD-2400000	Type	Method	Ref	HJD-2400000	Type	Method	Ref
47565.3737	II	pe	1	53318.9165	I	ccd	18
47823.5048	I	pe	1	53656.5685	I	ccd	19
47840.6360	I	pe	1	53668.8015	I	ccd	18
47850.4210	I	pe	1	53685.9293	I	ccd	18
47943.4012	I	pe	1	53739.7567	I	ccd	20
48222.3268	I	pe	1	53744.6506	I	ccd	20
48222.3276	I	pe	2	53766.6715	I	ccd	20
48299.4004	II	pe	2	53793.5857	I	ccd	20
48606.4669	I	pe	3	54055.3865	I	ccd	21
48650.5058	I	pe	3	54057.8341	I	ccd	20
49060.3247	II	pe	4	54073.7380	II	ccd	20
49372.2657	I	pe	5	54193.6316	II	ccd	22
49625.5031	II	pe	6	54400.3747	I	pe	23
49761.3046	I	pe	7	54402.8237	I	ccd	22
50047.5745	I	ccd	7	54408.9423	II	ccd	22
50079.3873	I	ccd	7	54433.4101	II	pe	23
50106.2985	I	ccd	8	54515.3736	I	ccd	24
50380.3383	I	pe	9	54764.9392	I	ccd	22
51185.3277	I	pe	10	54764.9399	I	ccd	22
51373.7390	I	ccd	11	54774.7265	I	ccd	22
52250.9000	II	ccd	12	54786.9621	I	ccd	22
52266.8056	I	ccd	12	54801.6414	I	ccd	22
52276.5957	I	ccd	12	54812.6523	II	ccd	22
52287.6027	II	ccd	12	54816.3222	I	ccd	25
52288.8255	I	ccd	12	54840.7874	I	ccd	22
52589.7781	I	ccd	12	54840.7884	I	ccd	22
52644.8308	II	ccd	13	54845.6802	I	ccd	22
52724.3527	I	ccd	14	54845.6826	I	ccd	26
52907.8584	I	ccd	13	54867.7018	I	ccd	22
52949.4538	I	ccd	15	54867.7024	I	ccd	22
52949.4565	I	ccd	16	55158.8543	I	ccd	27
53032.6433	I	pe	17	55169.8635	II	ccd	27
53317.6900	II	ccd	18	55185.7682	I	ccd	27

Table A.1 Continued from the previous page

55201.6755	II	ccd	27	55563.7765	II	ccd	27
55245.7097	II	ccd	27	55573.5628	II	ccd	27
55432.8751	I	ccd	27	55579.6804	I	ccd	29
55443.8859	II	ccd	27	55590.6906	II	ccd	27
55459.7893	I	ccd	27	55599.2520	I	ccd	30
55476.9162	I	ccd	27	55847.6067	II	ccd	31
55476.9168	I	ccd	28	55848.8258	I	ccd	32
55481.8093	I	ccd	27	55848.8265	I	ccd	32
55497.7146	II	ccd	27	55852.4969	II	ccd	31
55498.9346	I	ccd	27	55865.9522	I	ccd	32
55498.9364	I	ccd	27	55865.9527	I	ccd	32
55503.8308	I	ccd	27	55868.3970	I	ccd	31
55508.7236	I	ccd	27	55875.7404	I	ccd	32
55509.9476	II	ccd	27	55940.5796	II	ccd	32
55514.8421	II	ccd	27	55946.6960	I	ccd	32
55519.7355	II	ccd	27	56221.9605	II	ccd	33
55536.8653	II	ccd	27	56232.9677	I	ccd	34
55557.6609	I	ccd	27	56324.7231	II	ccd	33
55563.7761	II	ccd	27				

References: ¹Agerer & Lichtenknecker (1991), ²Hübscher et al. (1991), ³Hübscher et al. (1992), ⁴Hübscher et al. (1993), ⁵Hübscher et al. (1994), ⁶Agerer & Hübscher (1995), ⁷Agerer & Hübscher (1996), ⁸Agerer & Hübscher (1997), ⁹Agerer & Hübscher (1998), ¹⁰Agerer et al. (1999), ¹¹Paschke (1999), ¹²Lacy (2002), ¹³Lacy (2003), ¹⁴Agerer & Hübscher (2003), ¹⁵Kotkova & Wolf (2006), ¹⁶Zejda (2004), ¹⁷Lacy (2004), ¹⁸Lacy (2006), ¹⁹Brát et al. (2007), ²⁰Lacy (2007), ²¹Hübscher & Walter (2007), ²²Lacy (2009), ²³Yilmaz et al. (2009), ²⁴Hübscher et al. (2009a), ²⁵Hübscher et al. (2009b), ²⁶Diethelm (2009), ²⁷Lacy (2011), ²⁸Diethelm (2011a), ²⁹Diethelm (2011b), ³⁰Hübscher et al. (2012), ³¹Liakos & Niarchos (2011), ³²Lacy (2012), ³³Lacy (2013), ³⁴Diethelm (2013)

